32nm Node Device Laser-bandwidth OPE Sensitivity and Process Matching

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ABSTRACT

For 32 nm Node Logic Device, we studied the effect of laser bandwidth variation on Optical Proximity Effect (OPE) by investigating through-pitch critical dimension (CD) performance. Our investigation evaluated CD performance with and without the application of Sub-resolution Assist Features (SRAF). These results enabled us to determine the Iso-Dense Bias (IDB), and sensitivity to laser bandwidth, for both SRAF and no-SRAF cases, as well as the impact on Process Window. From the IDB results we present the required laser bandwidth stability in order to maintain OPE variation within CD Budget tolerances. We also introduce OPE matching results between different generation Immersion Lithography exposure tools evaluated for 45nm Node Logic Device.

Keywords: Iso-Dense Bias, laser bandwidth, E95, OPE, SRAF

1. INTRODUCTION

Process Control requirements are rapidly scaling commensurate with the relentless pace of device shrink they are being designed for. A prime example of this is the continuing control required for Iso-Dense Bias (IDB) and through-pitch performance. IDB performance can be attributed to numerous factors that generate changes in image contrast or induce focus blur. Until fairly recently, maintenance of IDB has been confined to illumination condition adjustment. However, through simulation and experimental results, it is now apparent that a more comprehensive overall methodology including other factors, such as laser light source spectral bandwidth (E95%), needs to be employed to fully compensate for IDB variation to the level required at advanced process nodes.[1]-[5]

In our previous investigation, we studied the sensitivity of IDB and through-pitch performance with regards to laser spectral bandwidth for both 55nm Node logic device [6] and 45nm Node logic device.[7] These results showed that for IDB change of 1nm, E95% variation was 85fm/nm and 69fm/nm, for 55nm and 45nm Logic Devices respectively. Increasingly higher spectral bandwidth stability is required for each successive technology node. This indicates that the 32nm Node will demand even tighter bandwidth control and the added ability to set spectral bandwidth with both high accuracy and flexibility.

Based on our prior results, in this investigation we verify the IDB sensitivity and through-pitch performance of 32nm Node Devices on Hyper NA exposure tool. Additionally, we evaluate an OPE matching strategy for 40nm Node Devices. OPE matching between different exposure tool sets must take into consideration the various factors contributing to tool-to-tool variation, such as the numerical aperture of projection optics and chromatic aberration.

In the 2008 ITRS Roadmap update, the required MPU Gate CD control is below 2.8nm. Fig. 1 shows the estimated CD Budget for a gate layer of 32nm Node Logic Device. Of this 2.8nm allotted CD variation, 1.28nm is attributable to exposure tool focus-related factors. Further detailed breakdown reveals the CD variations attributable to both chromatic aberration and laser bandwidth is 0.5nm.

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CD variation (3 sigma)		2.8nm
Scanner Induced	Focus	1.28nm
	Dose	0.94nm
Track Induced	PEB	0.6nm
	Development	0.4nm
Resist		0.94nm
Mask		1.5nm
OPC		0.94nm
Etching		0.9nm

Focus variation contributors	1.28nm
Wafer flatness	0.48nm
Reticle deformation	0.64nm
Focus & Leveling	0.8nm
Aberration	0.32nm
Chromatic aberration & Laser bandwidth	0.5nm

Fig. 1 CD Budget of 32nm Node Logic Device

2. SIMULATION FITTING THROUGH OPE MATCHING

First we performed simulations and experiments to verify OPE Matching between different generation exposure tools. The exposure conditions and simulations conditions are shown in Table 1 and Table 2, respectively.

Table 1 Experimental conditions for OPE matching

Item	Conditions
Exposure tool	Tool A: ArF immersion, Max NA = 1.2 (Catadioptric), E95% laser bandwidth = 250 fm Tool B: ArF immersion, Max NA = 1.35 (Catadioptric), E95% laser bandwidth = 280 fm
Target pattern	65 nm Line with mask bias, pitch=130 ~ 1100 nm
Exposure settings	Tool A: NA 1.2 / σouter 0.9 / σinner 0.6 / un-polarized (annular) Tool B: NA 1.2 / σouter 0.9 / σinner 0.6 / un-polarized (annular) *Applied same illumination and projection optics conditions for both Tool A and B

Table 2 Simulation conditions for OPE matching

Item	Conditions
Exposure tool	Tool B: ArF immersion, Max NA = 1.35 (Catadioptric), E95% laser bandwidth = 280 fm
Target pattern	65 nm Line with mask bias, pitch=130 ~ 1100 nm
Exposure settings	NA 1.2 / σouter 0.9 / σinner 0.6 / un-polarized (annular)
Simulation model	Lumped parameter model with optimized parameters

This experiment was performed using the same illumination settings for both tool A and tool B. The experimental and simulation results are both shown in Fig.2.

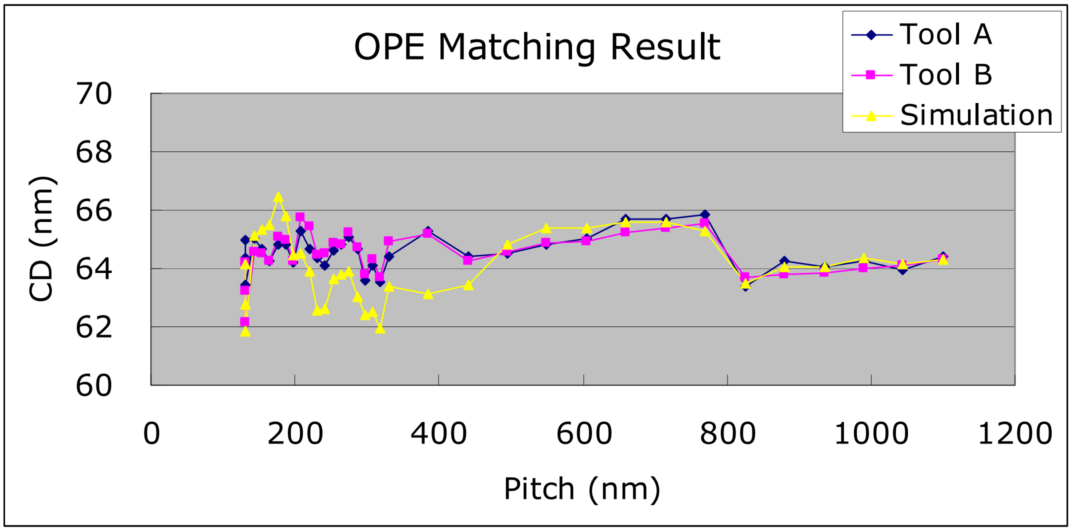

Fig.2 OPE matching result

The results show that with only the optimization of exposure dose, we could achieve OPE matching between tool A and tool B to within +/- 1.5nm. In addition, the difference between the simulation and tool B exposure results was within +/- 2.1nm, indicating a very high correlation. The simulation parameters derived here are in good agreement with the results from the combination of tool B and actual process conditions, thereby confirming the applicability of their usage for 32nm Node simulation under the same conditions.

3. INVESTIGATION RESULTS OF 32NM NODE LOGIC DEVICE

3.1 Simulation conditions

Next, using the simulation parameters derived during OPE matching, we performed a simulation for 32nm Node Logic Device. The simulation conditions are shown in Table 3.

Table 3 Simulation conditions for 32nm Node logic device

Item	Conditions
Exposure tool	ArF immersion, Max NA = 1.35 (Catadioptric), E95% laser bandwidth = 240, 360, 500 fm
Target pattern	45 nm Line with mask bias, pitch=90 ~ 900 nm, with and without SRAF
Exposure settings	NA 1.35 / σouter 0.9 / σinner 0.6 / XY-polarized (CQuad30°)
Simulation model	Lumped parameter model with optimized parameters

This simulation was also performed for conditions using SRAF. Table 4 shows the SRAF layout conditions. The SRAF size was 60nm on-reticle.

Table 4 SRAF Layout Rule

Pitch (nm)	Layout Position and Number
90≦P<180	No SRAF
180≦P<270	Centered between two lines
270≦P<450	SRAF placed at 90nm Pitch on inside of each line
450≦P	SRAF placed at 90nm and 180nm pitches respectively on inside of each line

3.2 Simulation results without SRAF

Here were present the simulation results for the no-SRAF case. Fig.3 shows the Through-Pitch CD trend for each E95% setting.

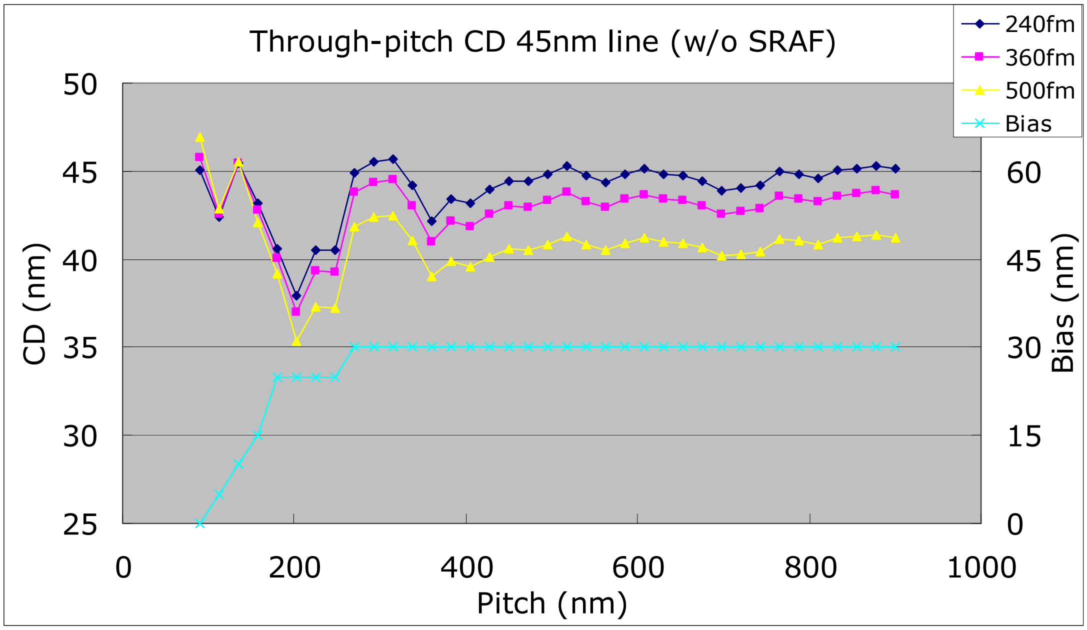

Fig.3 Through-pitch CD result (w/o SRAF)

These results shows that for Dense patterns, the CD variation is small across the range of E95%, however, for Isolated patterns, there is a reduction in CD with increasing E95%. In other words, IDB increases with increasing E95%, which confirms expected findings. The IDB trend derived from this data is shown in Fig.4.

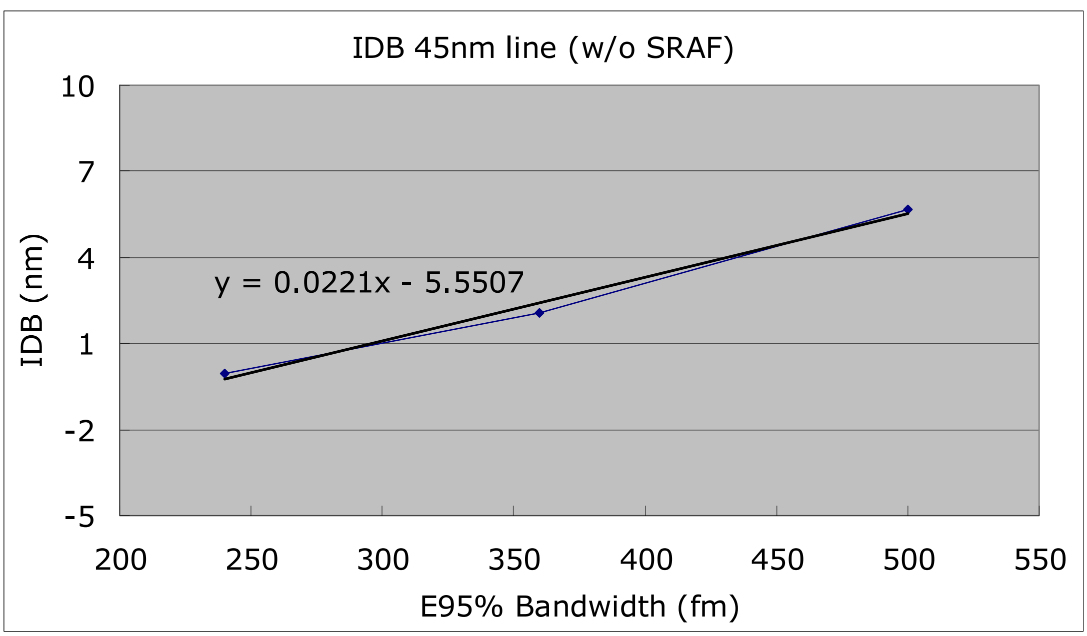

Fig.4 IDB result (w/o SRAF)

The IDB sensitivity was determined to be 0.0221nm/fm, which translates into E95% variation of 45.3 fm for 1nm of IDB change. Considering that the IDB change due to E95% for 32nm Node Logic Device is less than 0.5nm, E95% variation less than 22.6fm is required. Using E95%=240fm condition as reference, the impact of increasing E95% on process window is shown in Fig. 5 through Fig.7. Fig. 8 shows the DOF trend for EL set at 5%. The applicable pitches are 90nm, 180nm, 270nm, 450nm and 900nm.

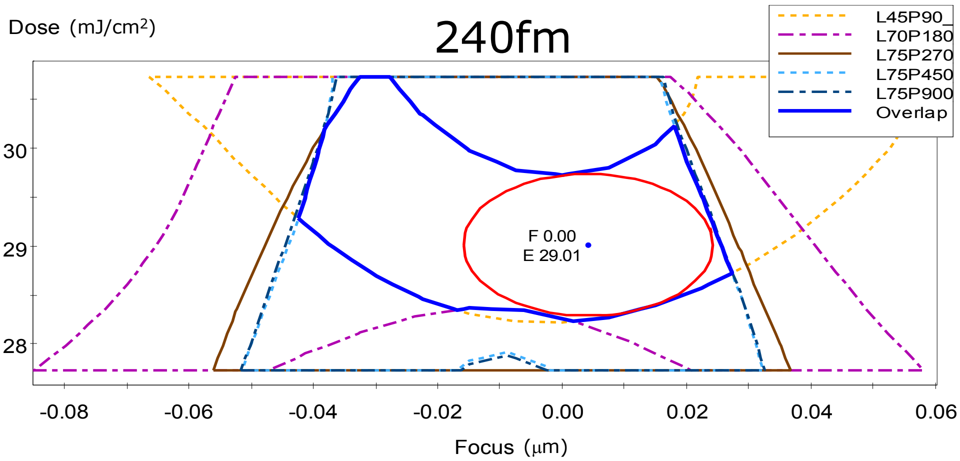

Fig.5 ED Window @ E95% = 240fm (w/o SRAF)

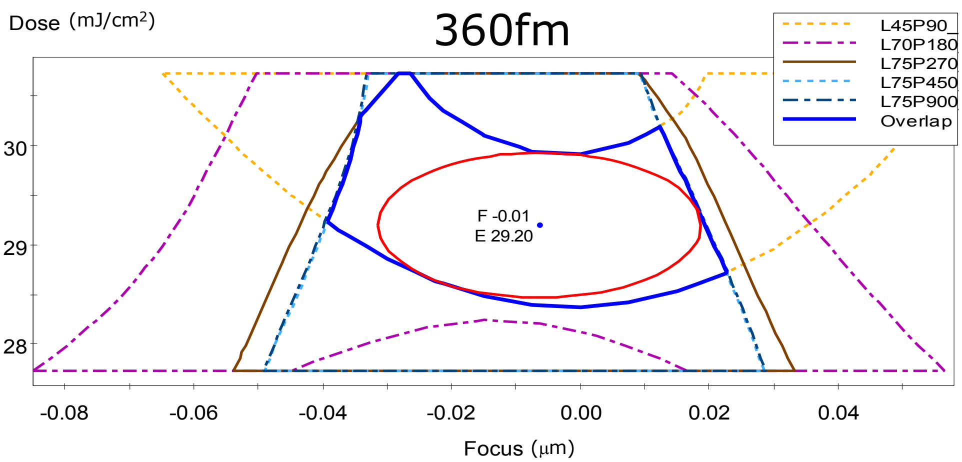

Fig.6 ED Window @ E95% = 360fm (w/o SRAF)

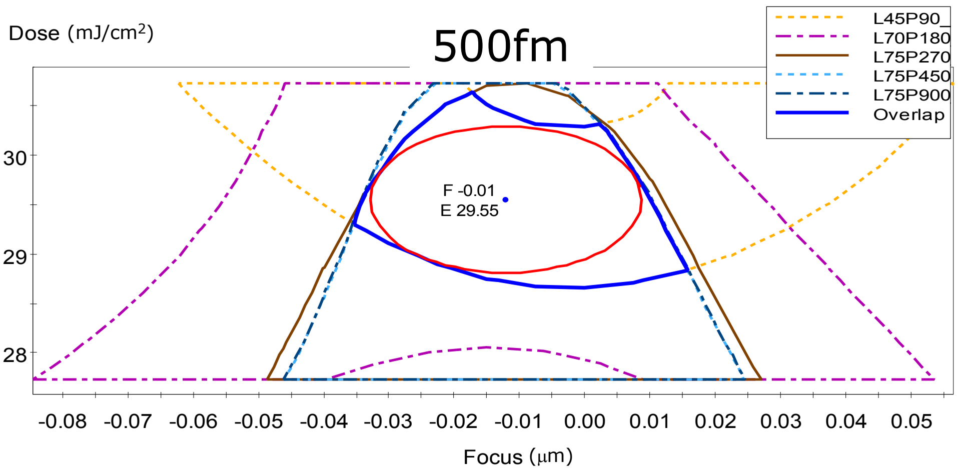

Fig.7 ED Window @ E95% = 500fm (w/o SRAF)

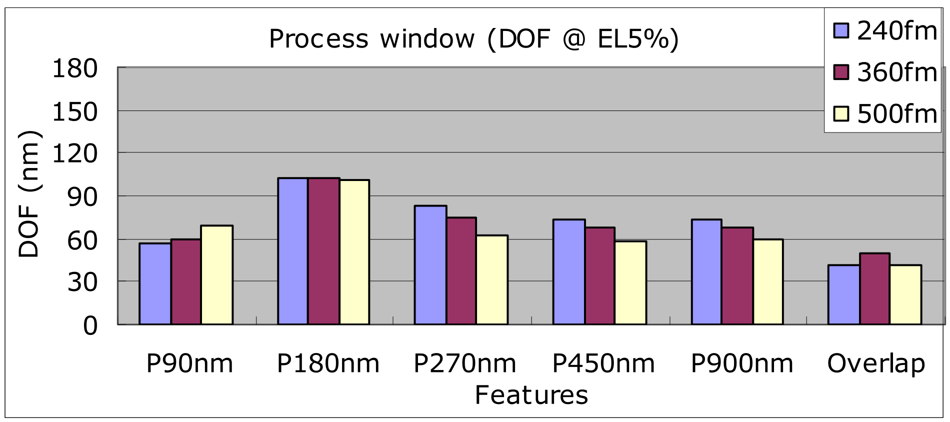

Fig.8 Summary of DOF @ EL5% (w/o SRAF)

For Dense patterns, DOF increases as E95% increases, however the trend reverses for Isolated patterns. The middle E95% setting of 360fm provided the largest overlapping Process Window across all pitches.

3.3 Simulation results with SRAF

We next present simulation results for the case where SRAF were employed. Fig.9 shows the Through-Pitch CD trend for each E95% setting.

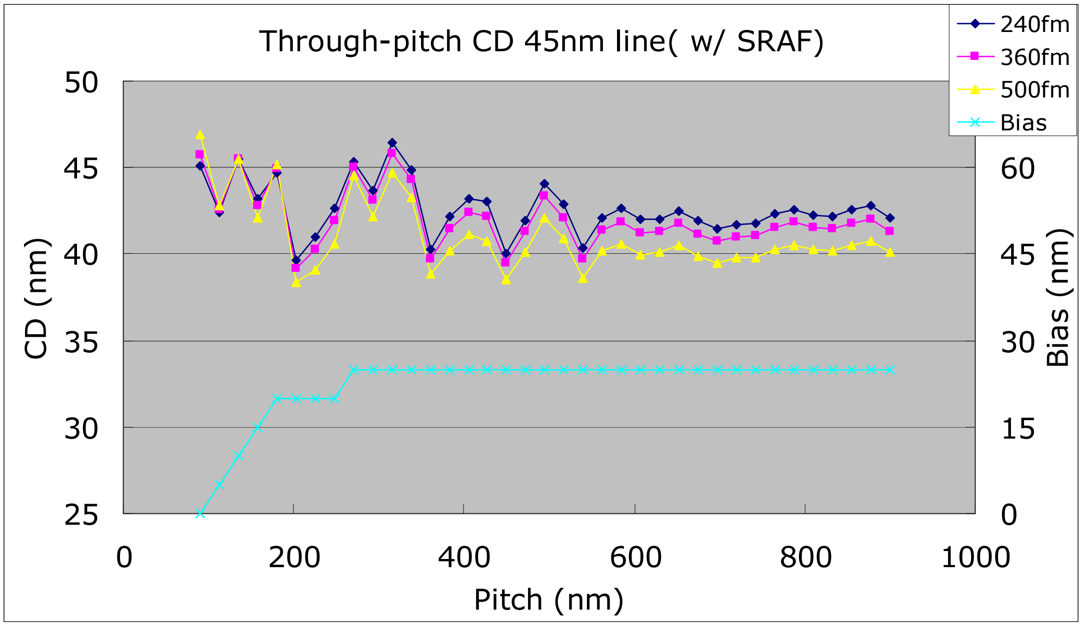

Fig.9 Through-pitch CD result (w/ SRAF)

For the SRAF case, we observe a similar trend to that of the no-SRAF case whereby as E95% increases, IDB also increases. The IDB sensitivity derived from these results is shown in Fig. 10.

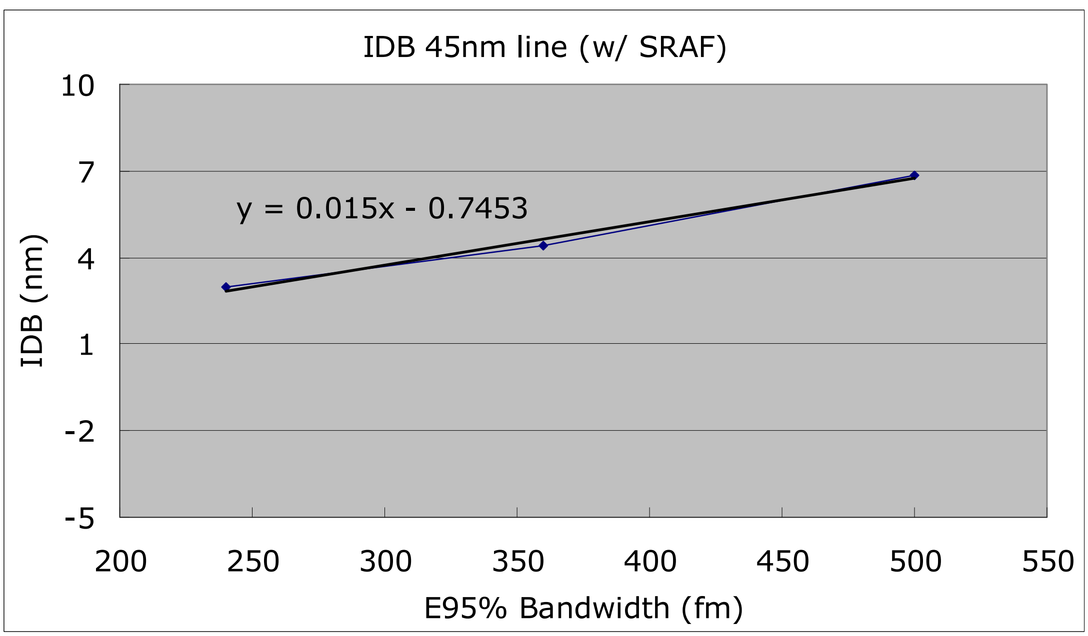

Fig.10 IDB result (w/ SRAF)

The IDB sensitivity to E95% for SRAF case is 0.015nm/fm, which equates to E95% variation of 66.7fm for every 1nm change in IDB. These results show that through the application of SRAF, we can reduce the IDB sensitivity to E95% for

32nm Node Logic Device by 32%. This confirms that the IDB sensitivity can be relaxed to the level of 45nm Node Logic Device. Based on the 32nm Node Logic Device budget requirement that IDB change due to E95% variation be less than 0.5nm, we can derive the required E95% variation to be within 33.4nm. As with the no-SRAF case, we determined the impact of increasing E95% on process window, using E95%=240fm condition as reference. The results are shown in Fig.11 through Fig.13. Fig. 14 shows the trend in DOF with constant EL of 5%. The applicable pitches are the same as with no-SRAF case: 90nm, 180nm, 270nm, 450nm and 900nm.

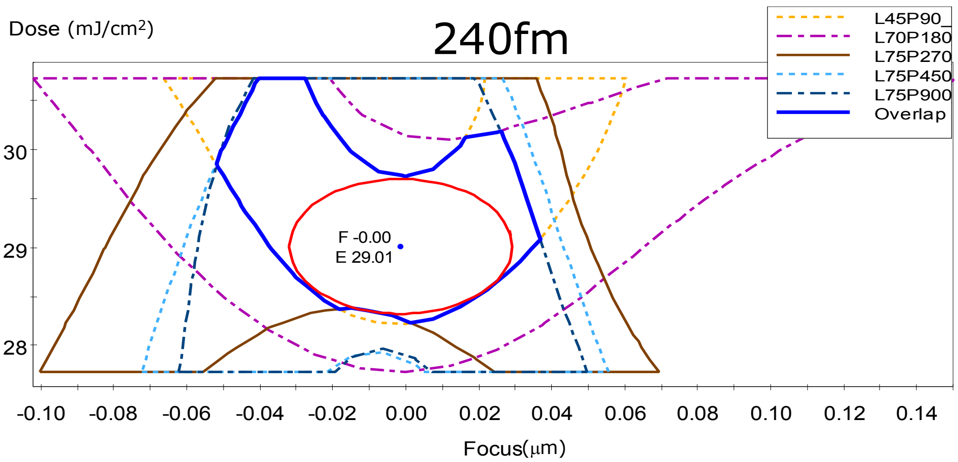

Fig.11 ED Window @ E95% = 240fm (w/ SRAF)

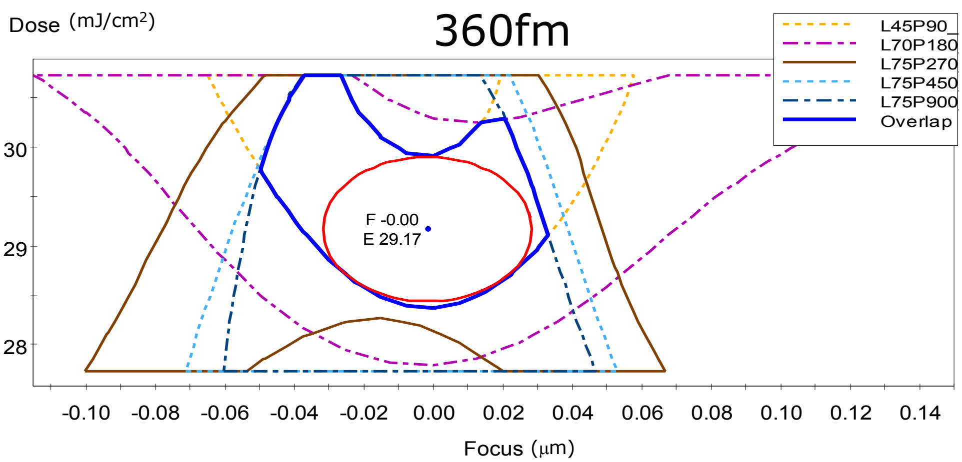

Fig.12 ED Window @ E95% = 360fm (w/ SRAF)

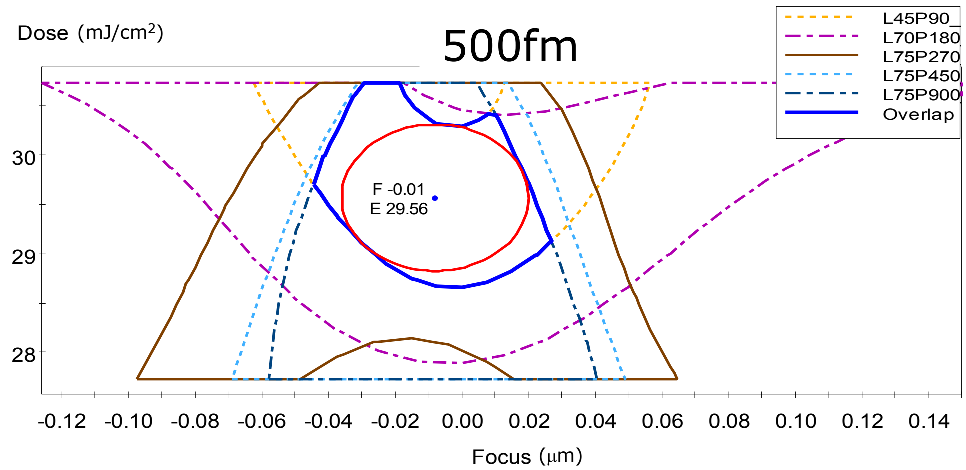

Fig.13 ED Window @ E95% = 500fm (w/ SRAF)

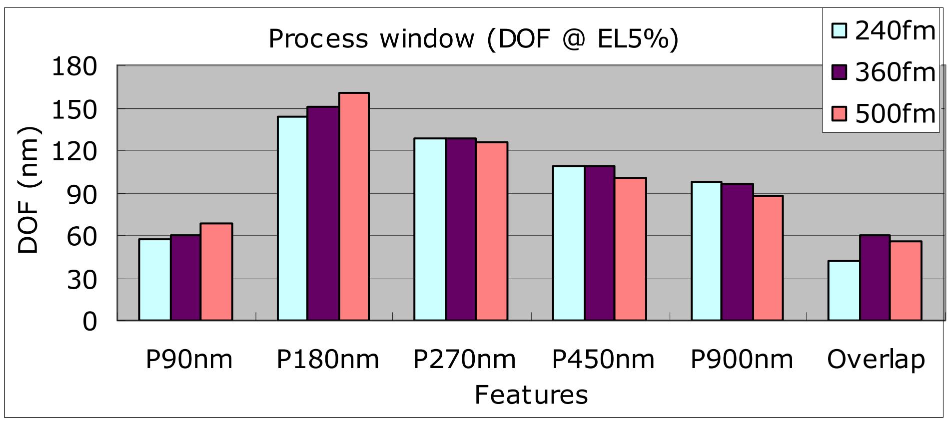

Fig.14 Summary of DOF @ EL5% (w/ SRAF)

For DOF, a pattern similar to the no-SRAF case was observed: for Dense patterns, DOF increases with increasing E95%, while the trend reverses for Isolated patterns. The overlapping process window across the multiple pitches was also maximized at the 360fm E95% setting. With the application of SRAF, there was an approximate 50% increase in DOF at the intermediate pitches, however, the overlapping Process Window showed almost no increase compared to the no-SRAF case due to the limiting narrow DOF for the densest patterns, which had no SRAF.

4. LATEST LASER LIGHT SOURCE PERFORMANCE

From the CD Budget analysis and experimental results thus far, we have shown that in order to maintain the IDB change due to E95% variation to within 0.5nm, laser light source E95% stability of less than 33.4fm is required. With regards this requirement, we present the most recent laser light source stability data. Fig.15 shows Cymer's XLR long-term E95% stability data taken over 6.5Bp in a High Volume Production Environment. The E95% variation during this time period was within 23fm, satisfying the stability requirements for 32nm Node Logic Device.

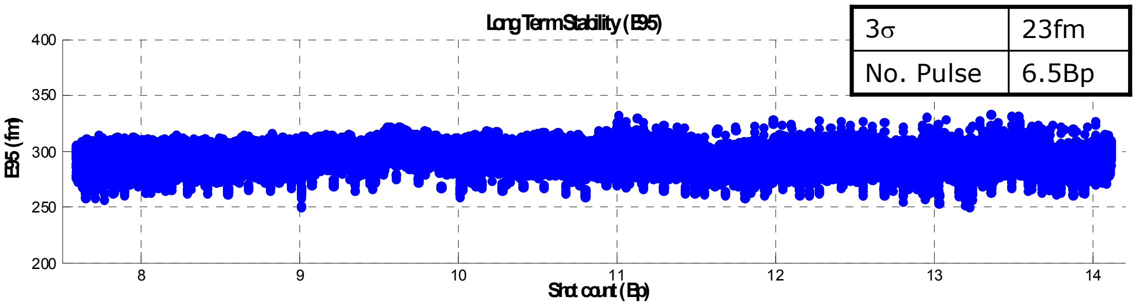

Fig. 15 E95% long-term stability of XLR

5. CONCLUSION

Simulation results show that, for the no-SRAF case, E95% variation of 45.3fm results in IDB change of 1nm for 32nm Node Logic Device

SRAF application enables E95% sensitivity for 32nm Node Logic Device to be relaxed to the level of 45nm Node Logic Device, 66.7fm.

From the CD Budget analysis, we have shown that CDU due to IDB variation for the 32nm Node Logic Device must be maintained within 0.5nm.

From this result we derive the laser light source stability requirement to be less than 33.4fm (3σ).

Simulation results have shown that Dense pattern DOF increases as E95% value increases, while Isolated pattern DOF exhibits opposite trend, decreasing with increasing E95%

Overlapping Process Window is maximized for current conditions by using the middle E95% bandwidth (360fm)

Through experimental results, we have shown the ability to easily perform OPE Matching between max NA1.35 and max NA1.20 exposure tools

Recent laser light source E95% stability of 23fm (3σ) is shown, which satisfies the performance requirements for 32nm Node Logic Device

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